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Correlates of Low-Level Lead Exposure in Urban Children at 2 Years of Age

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ABSTRACT. The blood lead levels of a large number of US preschool children approach the value regarded as the upper limit of normal. To reduce the number of children whose levels increase into the range thought to be toxic, the antecedents and correlates of levels in the 0- to 25-μg/dL range must be identified. In a large longitudinal study of middle and upper-middle class children living in metropolitan Boston, we evaluated how well five sets of variables predicted children's blood lead levels at 2 years of age: environmental lead sources, mouthing activity, home environment/care giving, prior developmental status, and sociodemographic characteristics. A series of bivariate and multivariate analyses indicated that only environmental lead sources and, to a lesser extent, mouthing activity accounted for significant portions of the variance in blood lead levels. Environmental lead sources were not significantly related to the home environment/care-giving variables or to sociodemographic characteristics. The most promising approach for achieving community-wide reductions in children's blood lead levels is reduction in the amount of lead in the proximate environment. *Pediatrics* 1986;77:826–833; *lead exposure, child development, hand-to-mouth activity, home environment.*

The maximum acceptable blood lead level for young children has been lowered three times since 1971.[1-3] As a result, the difference between the average level of general community exposure and the level considered to be the upper limit of the "safe" range has become progressively smaller. At present, the blood lead level of US children 6 months to 5 years of age is 16 μg/dL[4] and is within approximately .5 SD of 25 μg/dL, the current definition of an "elevated" level.[3] Shifting the distribution of population blood lead levels toward lower values would reduce the number of children whose levels increase into the clearly toxic range. If efforts to effect such a change are to be targeted most effectively, the correlates of blood lead levels in the range of 0 to 25 μg/dL must be identified. Recent evidence that blood lead levels below 25 μg/dL are associated with a variety of unfavorable hematologic,[5] electrophysiologic,[6] and cognitive[7,8] outcomes in children provides additional impetus to pursue this issue.

Factors that have been associated with childhood lead toxicity include elevated lead concentrations in various environmental sources,[9,10] maternal psychopathology and inadequate care giving,[11-14] social disadvantage,[15] and abnormal hand-to-mouth activity.[16] The generality of these findings is limited by two characteristics of the studies on which they are based. First, most were conducted on samples of children with clinical lead poisoning or moderate blood lead elevations (ie, >30 μg/dL). The correlates of the lower lead levels more representative of community exposure might not be the same as the correlates of levels that bring children to medical attention. Second, individual studies have tended to focus on one or two specific classes of predictors rather than on a broad range of possibilities. Substantial correlations among antecedents and correlates require that the association between any single risk factor and blood lead level be adjusted for these covariates.

We address these issues in this study and evaluate the contribution of environmental lead concentrations, children's mouthing behavior, maternal care taking, children's developmental status, and family sociodemographic characteristics to the relatively low (ie, <25 μg/dl) blood lead levels of a

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thumb/finger sucking. The second composite consisted of the four variables pertaining to children's mouthing of toys and other nonself objects.

Gallacher et al[19] have suggested that children's mouthing is associated with elevated blood lead levels only when environmental lead concentrations are high. To explore this hypothesis, interaction terms combining a child's score on the housedust lead composite and his or her score on each of the two mouthing composites were included in the analyses.

Set 3: Home Environment/Care-Giving Style (Six Variables). We included six psychosocial variables judged pertinent to a test of the hypothesis that the blood lead levels of the children in our sample vary inversely with the adequacy of care giving, particularly maternal availability and responsiveness. These included two scale scores from the Home Observation for Measurement of the Environment[20]: Scale I ("Emotional and Verbal Responsivity of the Mother") and Scale V ("Maternal Involvement With the Child" [HOME]). The other four scores were obtained from the Nursing Child Assessment Teaching Scales,[21] administered at 18 months of age: Scale I (the mother's sensitivity to her child's cues), scale III (the extent to which her teaching style fosters a child's social-emotional growth), and scale IV (the extent to which her style fosters a child's cognitive growth). Due to the child's lack of cooperation, these data could not be obtained for 25 mother-infant pairs. To avoid excluding these dyads from the analyses, we constructed a "dummy" variable coding the availability of these data ("no" = 0; "yes" = 1).

Set 4: Child Developmental Status (One Variable). Blood lead elevations might be associated with cognitive or emotional handicaps not because lead causes them but because children with these problems engage in behaviors such as pica that produce excess exposure to lead. To determine whether developmental status is associated with a child's subsequent blood lead level, we included as a predictor the mean of the Mental Development Index scores achieved at ages 18 and 24 months.

Set 5: Sociodemographic Factors (Nine Variables). A variety of family characteristics have been linked to blood lead elevations in children. In contrast to the variables in sets 1, 2, and 3, these variables are more likely to serve as markers of factors that more directly influence children's exposure to lead. The variables included in this set were family social class (Hollingshead's Four-Factor Index), parental marital status (unmarried = 0; married = 1), maternal and paternal education (Hollingshead's weighting), maternal intelligence,[24] number of children in the family, birth order of the index child, and family stress at 18 and 24 months.[25]

Statistical Methods

Four types of analyses are reported.

Bivariate Correlations Between the 23 Predictors and pb24.

Separate Multiple Regressions of pb24 on the Five Variable Sets. In these analyses, each set was considered individually, with no adjustment made for the association between infants' blood lead levels and the other variable sets.

Multiple Regression Analyses of pb24 Involving More Than One Variable Set. In these analyses, the variable sets were considered sequentially, in the order in which they are described in the previous section. This ranking is based on the relevance of the sets to children's day-to-day exposure to lead. The set pertaining to the lead content of various environmental sources is ranked first because a child living in a relatively lead-free environment is unlikely to accumulate a significant lead burden regardless of how much mouthing he does, how attentive and responsive his mother is, or his family's socioeconomic standing. Similarly, amount of mouthing activity is more likely to be a direct determinant of children's lead exposure than is maternal care-giving style or the children's overall developmental status.

We explored two approaches to the multiple regression analyses in which more than one variabl set was considered. (1) Nested regressions. Pb24 was regressed on variable set 1, then variable sets 1 and 2 combined, then sets 1, 2, and 3 combined, and so on until all five sets were included as predictors. At any step in the sequence, all predictors included in the equation competed directly with one another in a simultaneous regression analysis. (2) Hierarchical regressions. This series of analyses resembled the nested regressions except that, at any given step, the contributions of variables entered at an early stage of the analysis were not reevaluated in light of the contributions of variables entered at later stages. Rather, the dependent variable was the portion of pb24 not accounted for by all prior variable sets. For instance, the variance in pb24 not related to variable set 1 was regressed on variable set 2. The residuals from that analysis were regressed on variable set 3, and so on. Thus, at each stage, pb24 was adjusted for all prior variable sets.

Canonical Correlation Analyses of the Relationships Among Variable Sets. Specific hypotheses that have been advanced regarding the causal relationships among the different variable sets were considered. For instance, unfavorable care-giving practices (variable set 3) are thought to produce aber-

TABLE 2. Multiple Regression of Blood Lead Level at 2 Years of Age on Individual Variable Sets

Variable Set	Parameter Estimate	SE	P	Model F	P	Model R^2	N
Environmental lead							
Month of blood sample collection	.24	.13	.066				
Recent refinishing activity	.34	.11	.002	17.53	.0001	22.9	181
Dust lead content	.21	.04	.0001				
Mouthing activity							
Finger/thumb sucking	.11	.04	.002				
Toy mouthing	.03	.05	.51	2.62	.037	5.5	185
Finger/thumb sucking × dust lead	−.01	.03	.77				
Toy mouthing × dust lead	−.01	.03	.85				
Home environment/care-giving style							
Home Observation for Measurement of the Environment							
Scale 1	−.05	.05	.29				
Scale 5	.10	.04	.017				
Nursing Child Assessment Teaching Scales							
Scale 1	−.04	.06	.45	1.23	.29	3.9	187
Scale 3	.02	.05	.72				
Scale 4	−.01	.02	.78				
Dummy variable	.39	.57	.49				
Child developmental status: Mental Development Index	.002	.004	.64	0.22	.64	0.1	188
Sociodemographic characteristics							
Family social class	.06	.06	.28				
Maternal education	−.02	.03	.34				
Paternal education	.003	.03	.92				
Maternal intelligence	.004	.005	.34	0.91	.52	4.7	175
Parental marital status	.33	.38	.39				
No. of children in family	.02	.16	.90				
Birth order of index child	−.05	.17	.77				
Family stress							
18 mo	.07	.05	.15				
24 mo	−.06	.05	.24				

The contribution of month of sampling to the regression equation decreased slightly but progressively as additional sets of variables were added. This raises the possibility that a small part of its predictive value was shared by other variables.

The toy-mouthing variable hovered near the nominal significance level and appears to convey predictive information not possessed by the thumb/finger sucking variable. Among the 16 variables in sets 3, 4, and 5, only HOME scale 5 consistently contributed to the regression equation.

Hierarchical Regressions. These analyses, in which pb24 was adjusted for all preceding sets prior to assessing its association with any individual set, suggested the same conclusions as the nested regression analyses. Only set 2, the mouthing variables, produced even a marginally significant improvement in the predictive power of set 1.

Canonical Correlation Analyses

Many aspects of the relationships among variable sets failed to fit the patterns observed in children with higher blood lead levels. In canonical correlation analysis, variable weights are assigned in such a way that the multiple correlation between sets of variables is maximized. Despite this, neither the association between environmental lead and home environment/care giving nor the association between environmental lead and sociodemographic factors was statistically significant (Table 4). This suggests that the set of environmental lead variables carries minimal information about these psychosocial characteristics.

Children's mouthing activity was not significantly related to either of the variable sets containing features of the psychosocial environment. On the other hand, greater amounts of mouthing were associated with lower mean Mental Development Index scores. The strong relationships among home environment/care giving, child development, and sociodemographic factors are consistent with other studies of the correlates of early infant development.[28]

Pica typically refers to excessive mouthing or ingestion of nonfood items and is almost always present in cases of lead poisoning. For no child in our sample was mouthing behavior so extreme as to warrant application of this clinical term. Nevertheless, even variations within the normal range of mouthing activity were associated with children's blood lead levels. The mouthing activity most strongly related to blood lead level was thumb/finger sucking, although the contribution of toy mouthing approached statistical significance. The interaction factors combining housedust lead content and mouthing activity were not significant predictors, even when dust lead content, a strong predictor of pb24 as a single factor item, was not in the regression equation. Thumb/finger sucking appears to provide information even when dust lead content is in the equation. We interpret these findings as evidence of a dust lead content effect, regardless of a child's tendency to engage in hand-to-mouth activity. Similarly, increased amount of such activity is associated with higher blood lead levels even when dust lead levels are relatively low.

The developmental environments of the children with higher blood lead levels were not characterized by the care-giving inadequacies and the sociodemographic disadvantage common among children suffering clinical lead intoxication. Children in families experiencing higher levels of stress in the 6 to 12 months preceding blood sampling tended to have higher blood lead levels, but this association was not significant after blood lead levels were adjusted for other variables. The finding that scores indicating greater maternal involvement with the child (scale 5 of the HOME) were significantly associated with higher blood lead values stands in marked contrast to a large literature attesting that the risk of increased lead exposure is higher among children with less favorable care giving. The two variable sets associated with children's blood lead levels, environmental lead sources and mouthing activity, were not significantly related to quality of home-rearing environment or to sociodemographic characteristics. Despite the relative homogeneity of our sample in terms of socioeconomic standing, there was sufficient variability in care-giving quality and sociodemographic status to produce strong associations between these factors and the children's performance on the Bayley Scales. However, these variations were not related to the amount of lead in the children's immediate environments.

Several case-control studies of clinical populations have suggested that developmentally handicapped children are more prone than their peers to acquire toxic levels of lead,[22,23] prompting speculation that this model might account for the increased incidence of higher lead levels among children manifesting more subtle deficits. In our sample, children's Mental Development Index scores failed to predict later blood lead levels, suggesting that developmental scores in the lower portion of the normal range do not increase the likelihood of increased lead exposure, at least within the second year of life.

The mouthing variable set was significantly correlated with the composite variable reflecting developmental scores at 18 and 24 months. Several interpretations are possible. Mouthing could be an indicator of lower developmental scores and, therefore, an expression of immaturity. Another interpretation is that mouthing contributes to less optimal development via a lead effect or some other mechanism. When the interaction terms (dust lead content × thumb/finger sucking; dust lead content × toy mouthing) are excluded, the mouthing variable set is significantly correlated with the sociodemographic set.

Our findings should be considered in light of the characteristics of our subjects and their primary routes of exposure. Not only is our sample relatively homogeneous, but it is skewed to the upper end of the socioeconomic spectrum, consisting largely of families in which mothers are white, married, and relatively well educated. This reflects the catchment of the hospital whose delivery population we sampled, as well as our selection criteria, and the socioeconomic bias in loss-to-follow-up. The predictive power of certain variables may differ across geographic or cultural settings.

In general, the rearing environments of the children in our sample satisfy any reasonable standard of quality. The children's lead exposure may be regarded as a baseline, the more or less inevitable level of exposure that children experience by virtue of residence in a present-day metropolitan environment. Poor care giving or other risk factors associated with poverty might add to this baseline level of exposure, in some cases pushing a child's blood lead level into the clearly toxic range. For children who do become clinically ill, psychosocial intervention, as a component of the overall medical and environmental management plan, may reduce the likelihood of repeated intoxication. However, psychosocial factors appear relatively unimportant as determinants of variations in the levels typical of community exposure. The most promising strategy for achieving community-wide reductions in children's blood lead levels appears to be abatement of the lead sources themselves.

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